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Numerical Modeling of Metamaterials

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14. ABSTRACT
The goal of this project was to build a website containing a comprehensive review of available software packages for numerical modeling, design, characterization, and applications of metamaterials.

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					716-645-1031

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Report Title

ARO Final Report
Numerical Modeling of Metamaterials

ABSTRACT

The goal of this project was to build a website containing a comprehensive review of available software packages for numerical modeling, design, characterization, and applications of metamaterials.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

1. A. V. Kildishev, Y. Sivan, N. M. Litchinitser, and V. M. Shalaev, "Frequency-domain modeling of TM wave propagation in optical nanostructures with a third-order nonlinear response," Opt. Lett. 34, 3364-3366 (2009).
2. N. M. Litchinitser, and V. M. Shalaev, Metamaterials: transforming theory into reality, J. Opt. Soc. Am. B, Vol. 26, No. 12, pp.161-9 (2009).
3. A. V. Kildishev, and N. M. Litchinitser, Efficient simulation of non-linear effects in 2D optical nanostructures to TM waves, Opt. Commun. 283, 1628-1632 (2010).
4. I. Mozjerin, E.A. Gibson, E. P. Furlani, I. R. Gabitov, and N. M. Litchinitser, Electromagnetic Enhancement in Lossy Optical Transition Metamaterials, in press (Opt. Lett.).

Number of Papers published in peer-reviewed journals: 4.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals:

(c) Presentations

N. M. Litchinitser, I. Mozjerin, T. Gibson, M. Pennybacker, I. R. Gabitov, Transition Metamaterials, SIAM Conference on Nonlinear Waves and Coherent Structures (NW10), 2010, Philadelphia, Pennsylvania, USA.
N. M Litchinitser, T. Gibson, G. Venugopal, M. Pennybacker, I. Mozjerin, I. R Gabitov, Nonlinear Optics in Transition and Negative Index Metamaterials, Special Session on Strongly-nonlinear Phenomena: Theory and Applications to Nonlinear Optics, Hydrodynamics, Bose--Einstein Condensation and Biology, Albuquerque, NM 2010.

Number of Presentations: 2.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

1. I. Mozjerin, T. Gibson, E. P. Furlani, I. R. Gabitov, and N. M. Litchinitser, "Electromagnetic Field Enhancement in Realistic Transition Metamaterials," in Quantum Electronics and Laser Science Conference, OSA Technical Digest (CD) (Optical Society of America, 2010), paper QThB2.
2. N. M. Litchinitser, I. Mozjerin, T. Gibson, E. P. Furlani, I. R. Gabitov, Electromagnetic Enhancement in Lossy Optical Transition Metamaterials, LPHYS'2010, Brazil.
3. T. Gibson, I. Mozjerin, and N. M. Litchinitser, Transition Metamaterials: Theory and Design Optimization, LPHYS'2010, Brazil.
4. N.M. Litchinitser, T. Gibson, I.R. Gabitov, A.I. Maimistov, and V.M. Shalaev, Inhomogeneous and Guided-Wave Metamaterials: Linear and Nonlinear Optics AIP Conf. International Conference on Numerical Analysis and Applied Mathematics 2009.
5. T. Gibson, M. Pennybacker, I. Mozjerin, I. Gabitov V. Shalaev, N. Litchinitser, Design Optimization of Transition Metamaterials, Photonic Metamaterials and Plasmonics (META), Tucson, AZ (2010).

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts): 5

(d) Manuscripts

1. E. A. Gibson, M. Pennybacker, A. I. Maimistov, I. R. Gabitov, and N. M. Litchinitser,Resonant Absorption in Transition Metamaterials: Parametric Study, submitted to J. Opt. (2010).

Number of Manuscripts: 1.00

Patents Submitted

Patents Awarded

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Natalia Litchinitser	0.08	No
FTE Equivalent:	**0.08**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: ......

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:......

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:......

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale): ......

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering: ......

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense ......

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: ......

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
Vladimir Shalaev (consultant $2,000)	No
Vladimir Iakhnine (consultant $9,000)	No
Alexander Kildishev (consultant $2,00(	No
FTE Equivalent:	
Total Number:	**3**

Sub Contractors (DD882)

Inventions (DD882)

ARO Final Report
Numerical Modeling of Metamaterials

Principal Investigator: N. M. Litchinitser
Web Designer: V. Z. Iakhnine

Consultants: V. M. Shalaev, A. V. Kildishev

1. Objective

The goal of this project was to build a website containing a comprehensive review of available software packages for numerical modeling, design, characterization, and applications of metamaterials.

2. Summary

We have developed a website on Numerical Modeling of Metamaterials (http://optical-waveguides-modeling.net/metamaterials/ to be released September 2010) that contains:

- Metamaterials Tutorial (as illustrated in Fig. 1), which summarizes basic concepts of light propagation in optical metamaterials, magnetic and negative index metamaterials, major challenges and approaches to numerical modeling of metamaterials, including numerical studies of nonlinear metamaterials, multiscale modeling, materials' parameters retrieval procedures, optimization algorithms and a summary of proposed applications of metamaterials;

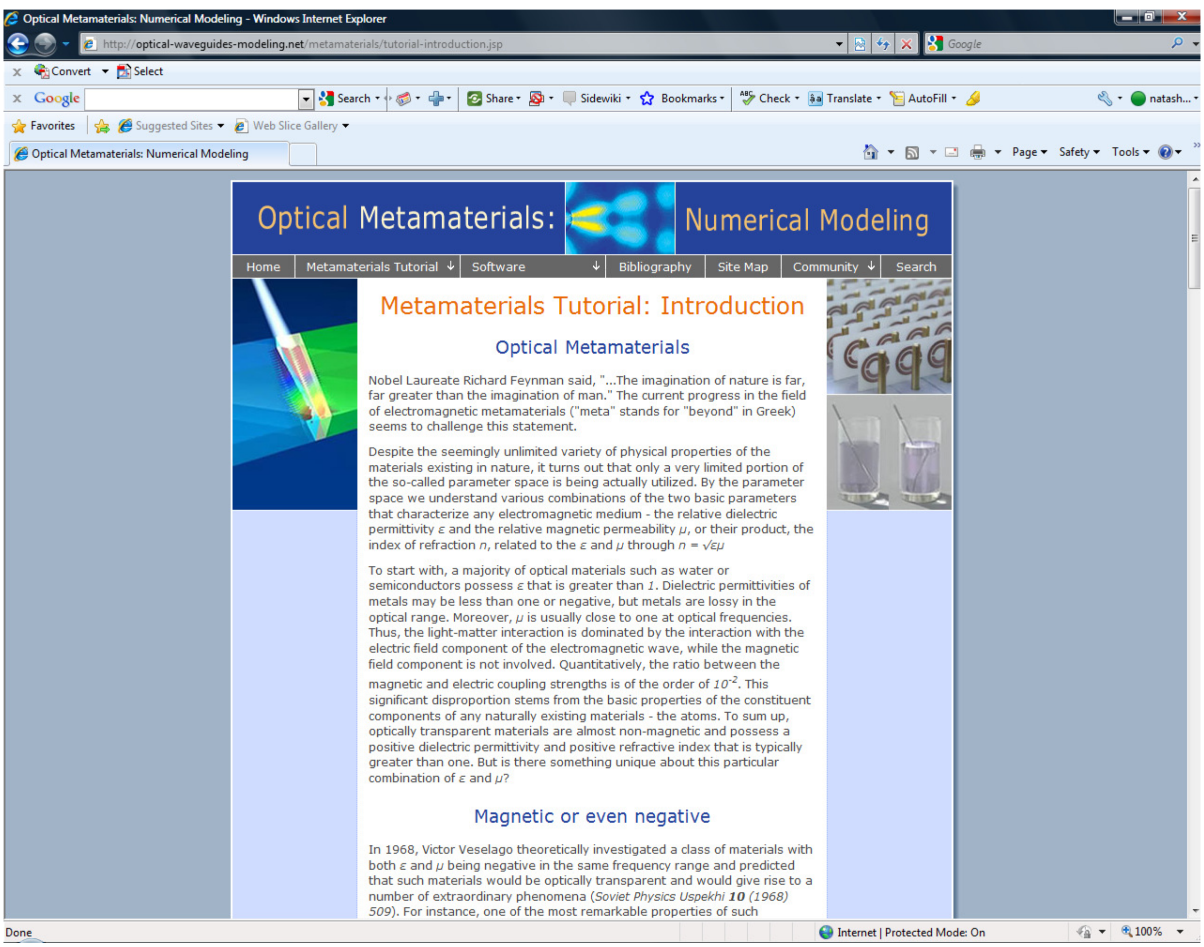

Figure 1. Metamaterials Tutorial page

- A broad collection of the software available for numerical simulations of metamaterials structures, supplied with a short summary of its capabilities and potential applications, a list of references to research papers that utilize a particular software package, and a link to the software provider's page.
- We provide the visitors of our website with an online file-sharing facility to be used to exchange simulation codes, documentation, and other relevant information. This facility is a first step toward building an online research community with its members sharing news, scientific expertise, and knowledge in the rapidly developing field of optical metamaterials modeling.
- The website contains a number of simulations demos as well as a link to a number of simulation tools available on nanoHUB.org
- Near term future plans include creating a discussion group and an online forum.

3. Website Structure Overview

The website contains the following pages: Home, Metamaterials Tutorial, Software, Bibliography, Site Map, Community, and Search. The front page contains a “Welcome” message and a brief introduction to the website structure. It also includes a “News” section with announcements of recent breakthroughs in the field of metamaterials and a list of upcoming research meetings, workshops, and conferences related to metamaterials and plasmonics.

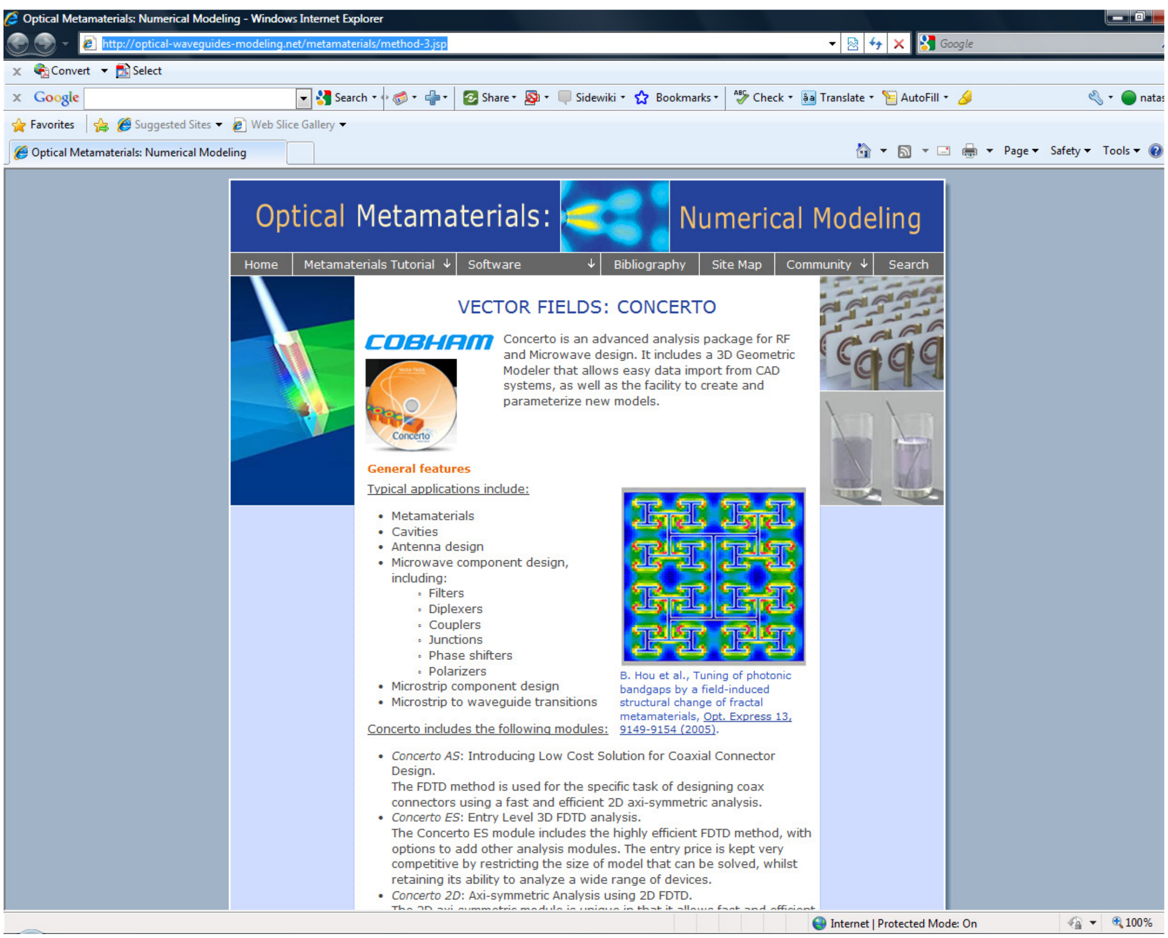

Figure 2. An example of software description page (providing a general description of the software, typical applications and basic modules).

The Software page is a key part of the website. It contains an extensive collection of software packages for various types of metamaterials simulations, including linear and nonlinear wave propagation, frequency and time domain methods, including finite difference time domain method, finite elements method, method of moments, and eigenmode solvers, a description of typical applications of a particular software package, hardware requirements, and some useful references, as shown in Figs. 2 and 3.

For users who are new to the field of metamaterials, we offer a short Metamaterials Tutorial, which summarizes basic concepts of light propagation in metamaterials, metamaterials design, optimization, and characterization.

We compiled a Bibliography that contains many useful references about metamaterials, plasmonics, nonlinear optics, and other general references on nanophotonics and nanotechnology.

The website is also supplied with a Site Map for easier navigation through the site, a "community" section, providing an online file-sharing facility to be used to exchange simulation codes, documentation, and other relevant information, as well as a search engine, enabling visitors to explore the site with the keywords of their choice.

In addition to the detailed description of the software available on the web, the website contains a summary of modeling tools developed largely by Purdue University researchers and students that is available on Nanohub, as shown in Fig. 4. We summarize the basic features of the tools related to numerical modeling of metamaterials and plasmonic nanostructures, and provide a link to the tool itself. One of the scientific consultants involved in this project, Dr. A. V.

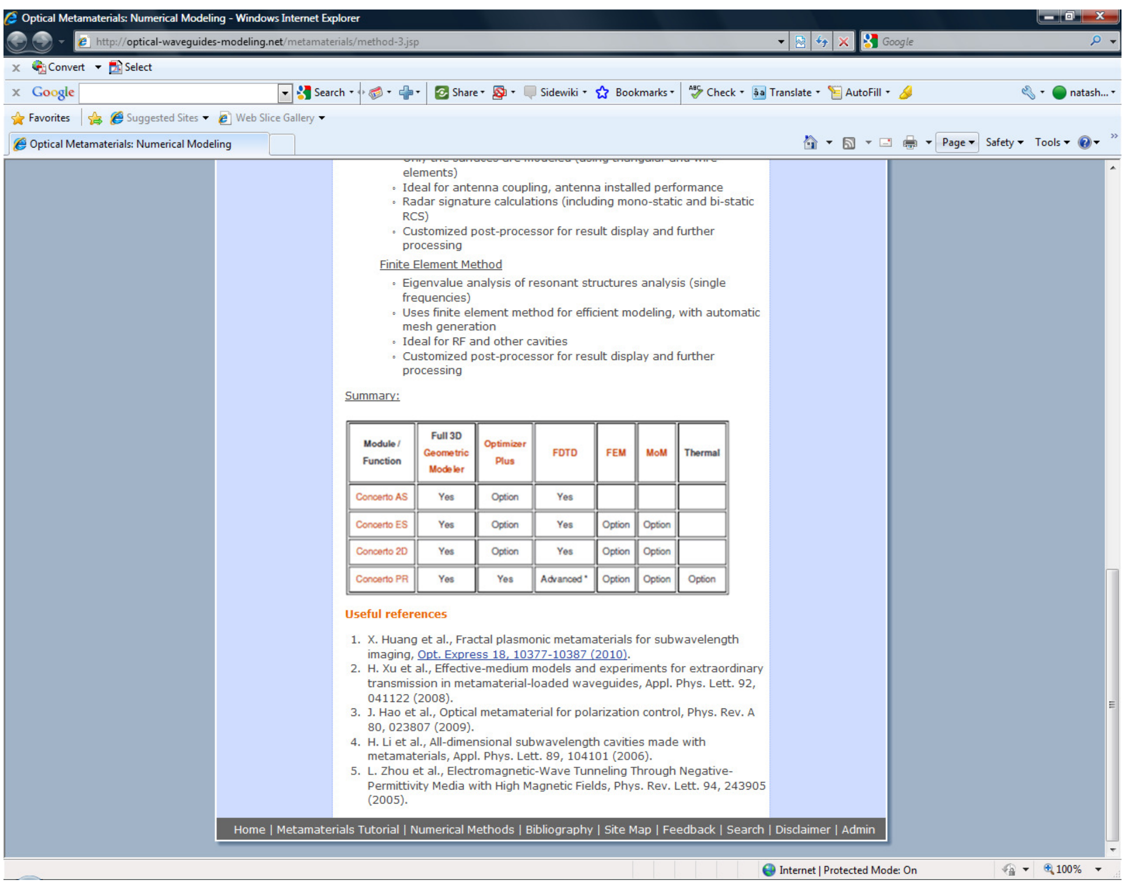

Figure 3. An example of software description page (providing a description of numerical methods implemented in this particular software package, a summary of different features, and some useful references).

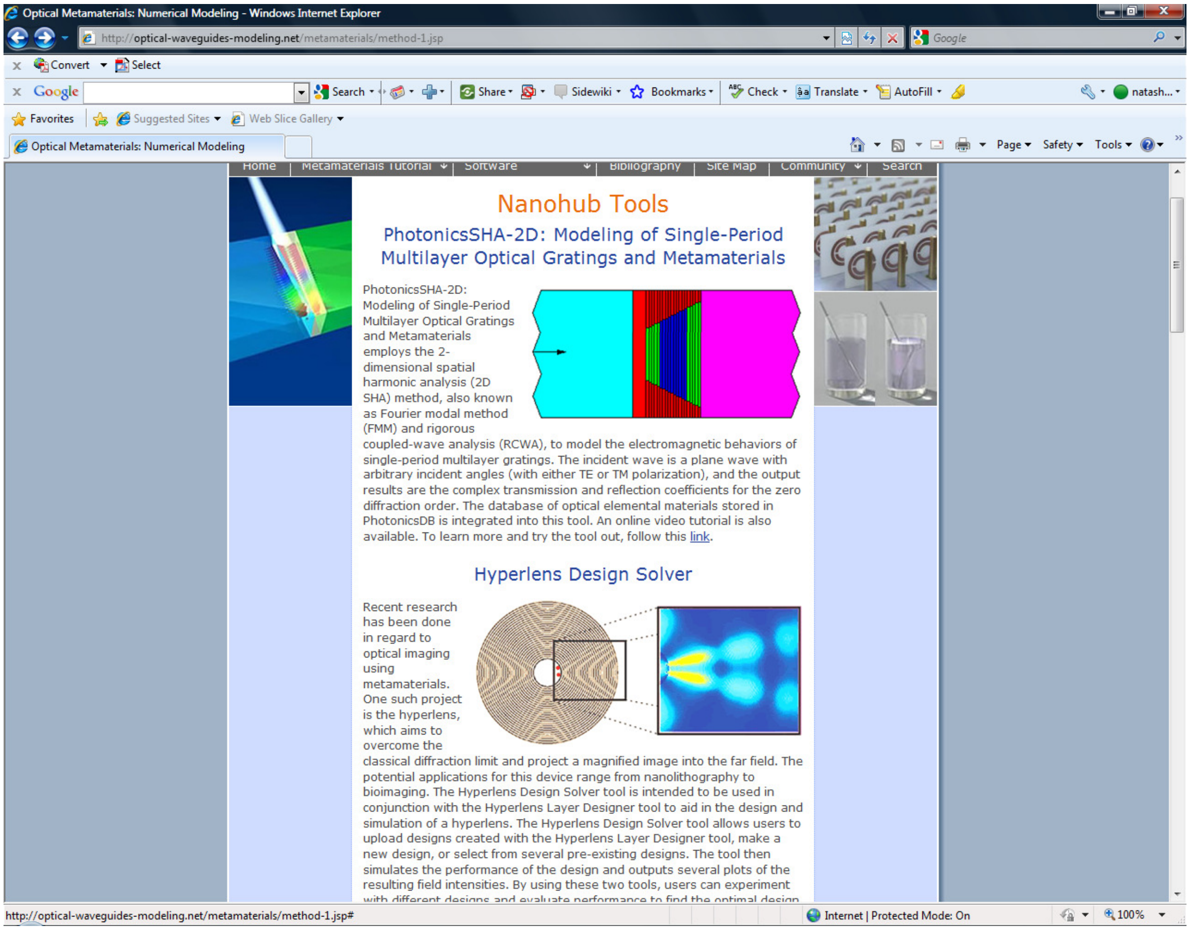

Figure 4. A summary of Nanohub tools with links.

Kildishev, has developed a number of tools available on Nanohub, and therefore, our website users will be able to obtain a detailed advice and guidance regarding those tools, if needed.

Finally, several online demos have been developed enabling our users and visitors to watch demo-simulations of such fascinating metamaterials-based devices as a cloak or a hyperlens,

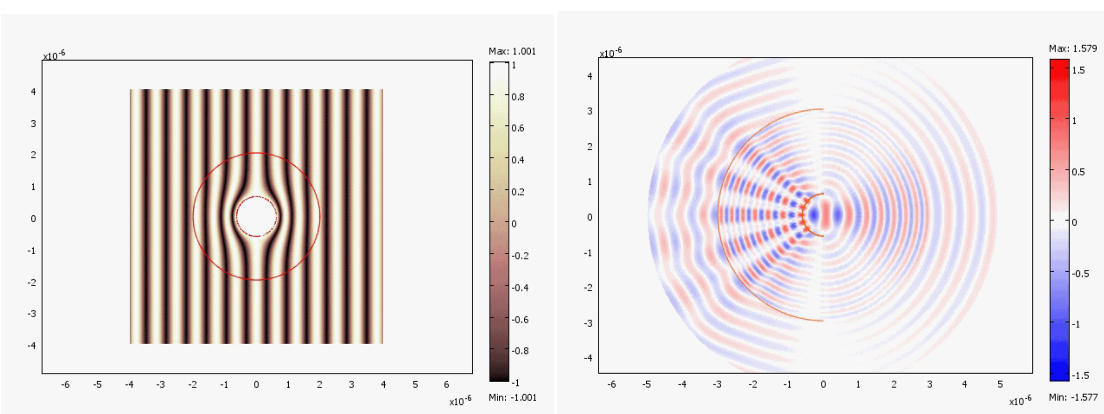

Figure 5. Examples of online demos for a cloak (left) and a hyperlens (right).

as shown in Fig. 5.

The metamaterials modeling website will be continuously maintained, including regular content updates (e.g., adding new tools as they become available), small-to-medium page redesigns (e.g., incorporation of a videostream, a slide show, or another media type), and creation of new pages, as needed, with subsequent modification of the site navigation. Usage statistics of the sites will be monitored and analyzed, as well as sites' ranking by major search engines.

Publications/presentations resulted from this project:

A. V. Kildishev, Y. Sivan, N. M. Litchinitser, and V. M. Shalaev, "Frequency-domain modeling of TM wave propagation in optical nanostructures with a third-order nonlinear response," Opt. Lett. 34, 3364-3366 (2009).

N. M. Litchinitser, and V. M. Shalaev, Metamaterials: transforming theory into reality, J. Opt. Soc. Am. B, Vol. 26, No. 12, pp.161-9 (2009).

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I. Mozjerin, T. Gibson, E. P. Furlani, I. R. Gabitov, and N. M. Litchinitser, "Electromagnetic Field Enhancement in Realistic Transition Metamaterials," in Quantum Electronics and Laser Science Conference, OSA Technical Digest (CD) (Optical Society of America, 2010), paper QThB2.

N. M. Litchinitser, I. Mozjerin, T. Gibson, M. Pennybacker, I. R. Gabitov, Transition Metamaterials, SIAM Conference on Nonlinear Waves and Coherent Structures (NW10), 2010, Philadelphia, Pennsylvania, USA.

N. M. Litchinitser, I. Mozjerin, T. Gibson, E. P. Furlani, I. R. Gabitov, Electromagnetic Enhancement in Lossy Optical Transition Metamaterials, LPHYS'2010, Brazil.

T. Gibson, I. Mozjerin, and N. M. Litchinitser, Transition Metamaterials: Theory and Design Optimization, LPHYS'2010, Brazil.

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N. M Litchinitser, T. Gibson, G. Venugopal, M. Pennybacker, I. Mozjerin, I. R Gabitov, Nonlinear Optics in Transition and Negative Index Metamaterials, Special Session on Strongly-nonlinear Phenomena: Theory and Applications to Nonlinear Optics, Hydrodynamics, Bose--Einstein Condensation and Biology, Albuquerque, NM 2010.

T. Gibson, M. Pennybacker, I. Mozjerin, I. Gabitov V. Shalaev, N. Litchinitser, Design Optimization of Transition Metamaterials, Photonic Metamaterials and Plasmonics (META), Tucson, AZ (2010).